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Population and habitat characteristics of rare moonworts (*Botrychium* subg. *Botrychium*) in Summit County, Colorado

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Final Report Submitted to the Dillon Ranger District
White River National Forest

25 September 2001

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1 Introduction

In recent years there has been an increased awareness and interest in moonworts, a group of ferns in the genus *Botrychium* subg. *Botrychium* (Ophioglossaceae). Since 1980, 15 new species have been described from the genus from North America, which is now the clear centre of diversity of the subgenus worldwide. This work has been largely due to the efforts of Warren H. and Florence Wagner, two plant systematists from the University of Michigan, Ann Arbor, who have dedicated much of their professional careers to the study of pteridophytes worldwide.

The objectives of the present project were 1) to summarize what is known of moonworts in Summit County, Colorado, 2) to identify threshold population levels for conservation purposes and 3) make recommendations for management.

2 About moonworts

Moonworts (*Botrychium* subg. *Botrychium*) are small, primitive ferns in the family Ophioglossaceae. There are about 28 species in the subgenus worldwide, with 22 species currently recognized as occurring in North America (Wagner & Wagner 1993, 1994), with description of several new species in preparation (Farrar 2000). Two other subgenera are found in North America: subg. *Osmundopteris*, sometimes regarded as a distinct genus (*Botrypus*, Weber & Wittmann 1992), and represented in Colorado by *B. virginianum*, and subg. *Sceptridium* (represented in Colorado by *B. multifidum*). Only subgenus *Botrychium* is treated here.

Moonworts differ from true ferns in that the sporophyte is divided into a fertile portion (sporophore), with grape-like clusters of sporangia which contain the spores, and a sterile, leafy portion (trophophore) which can be simple to pinnate or bipinnate, and whose shape, size, colour and texture are of great importance in the identification of species.

Like all cryptogams, moonworts reproduce by spores. The following discussion by Farrar (1998a) summarizes some of the important parts of moonwort reproductive biology:

> The sporophyte stage, which is what we see as above-ground leaves, produces spores which have half the number of chromosomes of the parent sporophyte. These spores germinate underground and grow into the gametophyte stage. Each gametophyte produces both male and female gametangia containing sperm and eggs. When mature, sperm are released and then swim to an egg with which they fuse to initiate the next sporophyte generation. All of these acts of sexual reproduction take place underground. We can readily imagine that travel through soil by swimming sperm must be considerably hindered relative to sperm swimming in liquid on the soil surface as is the case for most ferns. In the underground environment, sperm from one gametophyte plant may be unable to reach another gametophyte more than a few millimeters distant. They are quite capable though of reaching eggs of their own gametophyte which may be less than one millimeter away. The latter, however, constitutes self-fertilization.
>
> Because all cells of an individual gametophyte are derived from a single initial cell, the spore, sperm and eggs produced by that gametophyte are genetically identical. Fertilization of an egg by sperm from the same gametophyte unites identical genotypes. The resulting sporophyte has no genetic heterozygosity; neither does

> the spores it subsequently produces. Thus, with no means of maintaining or generating genetic variability (except by new mutation) sexual reproduction through self-fertilization becomes genetically equivalent to vegetative reproduction.
>
> .... Of more than 2000 individual *Botrychium* plants examined electrophoretically in our studies and those of several other researchers, less than 1% have shown heterozygosity from outcrossing. This observation provides strong support for the hypothesis that sexual reproduction in *Botrychium* is predominantly by self-fertilization.

According to Farrar (1998a), this process essentially results in cloning: multiple *Botrychium* individuals in a population may (and often do) belong to a single genotype. They may also, therefore, have similar morphological "marks". When a population consists of several genotypes, the patterns of these morphological "marks" may lead one to believe that there is more than one taxon involved.

Because of the fact that moonworts are in essence selfers, in-breeding and in-breeding depression, which are often issues in the conservation of isolated or small populations of rare plants (Oostermeijer et al. 1998), are not issues with *Botrychium*. This is because deleterious genes that are the cause of inbreeding depression in outcrossing species are quickly eliminated from the gene pool in habitually selfing species. Comparative seed production, often used as a measure of in-breeding depression in PVAs for plants, cannot be measured in *Botrychium*, which produces countless spores. Spore viability is also scarcely measurable.

Spore dispersal is accomplished by wind. Because moonwort spores are extremely tiny, they are probably distributed over long distances. Dispersal distance is unlikely to be a problem as it is in some heavy-seeded plants with dispersal limitations. It has also been speculated (W.H. Wagner, pers. comm. 1998) that moonwort spores may be in part distributed in animal excrement; ungulates have been observed to graze the sporophores of moonworts. Because of the ability of the gametophyte to self-fertilize, a single isolated spore can start a new population. This is not necessarily the case with out-breeding plant species.

There are few reports on life span of moonworts, but the available information points to short life spans. Lesica & Ahlenslager (1996) report an above-ground life span of 3 years in their monitoring study of *Botrychium hesperium*, *B. paradoxum* and *B. x watertonense* in Waterton Lakes National Park in Alberta. From the Vosges region of France, Muller (1993) reported a life span of only about 2 years for *Botrychium matricariifolium* once it had begun producing sporophores. Johnson-Groh (pers. comm.) estimates an average life span of about 5-6 years after the first above-ground appearance for species being studied in Minnesota. There have also been observations of moonworts on Copper Mountain in the present study area which were producing sporophytes on excavated surfaces only 2-3 years after disturbance (R. Thompson and N. Redner, pers. comm.).

3 Materials and Methods

The project work entailed both a field and synthetic portion. Field work was carried out throughout the month of August to survey existing, known populations and to try to find new populations of moonworts in Summit County, Colorado, mostly between 39°22'N and 39°53'N and 105°50'W and 106°23'W. Areas were visited where there were existing moonwort populations as well as previously unsurveyed areas recommended by people knowledgeable with the area, especially M. Liu and N. Redner. Surveys concentrated on areas near timberline, especially where there had been burns in the last 100 years. In order to characterize the plant communities in which moonworts occur, vegetation samples (relevés) were placed in homogeneous stands of vegetation in which *Botrychium* species were abundant or well-represented and preferably where diversity of *Botrychium* species was highest. Relevés followed standard phytosociological methods (Westhoff & van der Maarel 1978) and, with one exception, were 16m² and square. Thirteen such samples were gathered in the southern half of Summit County (Map 1). A vegetation synthesis table was produced using Excel and sorted manually. Taxonomy for most plants follows Weber & Wittmann (1992).

Population[1] sizes were estimated approximately due to the fact that 1) moonworts were usually extremely numerous in the sites surveyed and 2) many plants were already dried up at the time field work began due to the warm, dry weather and late time of year. Therefore, population sizes in some cases may actually be larger than estimated. Dried plants were frequently collected and rehydrated in boiling water to attempt identification. Already-sporulated plants were collected from nearly every site and pressed in phonebooks to provide a voucher specimen documentation of the species concepts adopted here and the species found at the various sites. In all, 33 sheets of *Botrychium* specimens were prepared and have been deposited with the Dillon Ranger District and the herbarium of the University of Colorado Boulder (COLO).

Fresh samples of three moonworts from Copper Mountain were sent to Donald Farrar (Iowa State University, Ames, Iowa) for enzyme electrophoretic analysis. These were determined to be samples of *Botrychium echo*, aberrant morphs of *B. minganense* and one highly unusual race, termed "parsley", treated in more detail later in this report.

Photocopied profiles of nearly all of the moonworts collected were sent to Florence Wagner, University of Michigan Ann Arbor, for verification. Unfortunately, no results are available for incorporation into the present report.

Population sizes were estimated visually and population estimates from work conducted by survey contractors was incorporated to develop an idea of abundance of the various species. New populations were documented on Colorado Natural Heritage Program survey forms.

A literature survey was accomplished particularly as concerns the topic of population viability of rare plants. What was found is summarized in this report and was incorporated in the

[1] Population, as used in this report, refers to individual sites.

consideration of conclusions and management recommendations. This report does not include the results of new moonwort surveys by other botanists in the summer of 2001.

4 Results and Discussion

4.1 Taxonomy and Habitats

Species of *Botrychium* subg. *Botrychium* are widespread in the northern hemisphere, but they have a clear epicentre of diversity in North America, particularily in western North America (Wagner & Wagner 1986). The causes of this endemism are not understood. The distribution patterns of Colorado moonwort species according to distributional type are given in Table 1.

Table 1. *Botrychium* species found in Colorado and their distribution types and global rankings according to the TNC, MNHP websites.

Species	Areal distribution type	Global rank
B. campestre	Great Plains	G3
B. echo	Southwestern North America	G2
B. hesperium	Western North America	G3
B. lanceolatum	Circumboreal	G5
B. lineare	(Northern?) North America	G1
B. lunaria	Circumboreal	G5
B. minganense	Northern North America	G4
B. pallidum	Northern North America	G2
B. "parsley"	?	
B. pinnatum	Northwestern North America	G4?
B. simplex	Circumboreal	G5

Global ranks:

G1 = Critically imperiled throughout its range due to extreme rarity (5 or fewer sites or very few remaining individuals) or extremely vulnerable to extinction due to biological factors;
G2 = Imperiled throughout its range due to rarity (6-20 sites or few remaining individuals) or highly vulnerable to extinction due to biological factors;
G3 = Either very rare and local throughout its range (21-100 sites), with a restricted range (but possibly locally abundant), or vulnerable to extinction due to biological factors;
G4 = Apparently secure throughout its range (but possibly rare in parts);
G5 = Demonstrably secure throughout its range (but possibly rare in parts).
(Source for G-ranks: Colorado Natural Heritage Program, http://www.cnhp.colostate.edu/docs/splist2.html, except *B. ascendens* obtained from Montana Natural Heritage Program, http://orion2.nris.state.mt.us/mtnhp/plants/index.html)

Species of *Botrychium* subg. *Botrychium* are notoriously plastic in morphology and thus difficult to identify, especially if one has not seen many in the field. A wide variety of morphological characteristics can be called upon to separate them, but unfortunately even these sometimes do not suffice in dwarf plants. Table 2 was constructed to help the field botanist to distinguish species using multiple characteristics.

Basically, any given specimen of moonwort can be placed into one of four groups: the fan-leaved or *B. lunaria* group, the pinnate-leaved group, the *simplex* group (consisting only of *B. pumicola* and *B. simplex, s.lat.*) and the *B. lanceolatum* group (consisting only of *B. lanceolatum*).

In addition to the recognized species, a number of moonworts were found which do not cleanly fit into any described taxon. One such form was found in the Keystone Ski Area (and a few plants at Copper Mountain) and was termed "parsley-leaved" *Botrychium*. It appears as a form of *B. lunaria* with widely-spaced, deeply lacerate pinnae, which are themselves rather thick and undulate. The fresh pinnae give the impression of parsley leaves. A single sample of this – or a plant which looked similar - from Copper Mountain, was sent to Donald Farrar for electrophoretic analysis. While the plant showed a distinct isozyme pattern with electrophoretic analysis, it was a degenerated late-season specimen, and fresh material would be needed to conclusively determine if it is in fact a distinct taxon.

Another anomalous plant collected during the field work was a form originally discovered in Oregon which was originally thought to have been a new species and at that time called *B. fenestratum* (Latin: *fenestra*, window), after the little window-like hole formed when the pinnae overlap upwards. This taxon has been since confirmed to be within the genetic variability of *B. hesperium* and not worthy of species rank (Farrar 2000). This is, as far as is known, the first report of this form from Colorado. The *fenestratum* form of *B. hesperium* has been confused with *B. pinnatum* in the field but lacks the red stem, bright green colour and angular pinnae of that species; like *hesperium*, the *fenestratum* form is matte and rather more pale, but the lobes tend to be more ascending and more dissected. The plant is also larger than the typical form of *B. hesperium*.

A key to the genus in Colorado has been prepared by Root (undated). This key, however, does not take into consideration some of the many forms of moonworts which have been encountered in the state. Writing a key that is useful in separating the various forms and correctly naming species is all but impossible, as correct identification requires a familiarity with the various forms of the species in the field.

Distribution of moonworts in Colorado has been shown in the Colorado Rare Plant Field Guide (Spackman et al. 1997) but these maps are hard to read and outdated. A set of maps showing the distribution of all members of *Botrychium* subg. *Botrychium* in Colorado is provided in Appendix B. It is based on Colorado Natural Heritage Program element occurrence data, herbarium specimens and recently acquired information in Summit and Lake Counties.

Table 2. Comparison of morphological characteristics in Colorado *Botrychium* (*B. ascendens* and *B. matricariifolium* are included for comparison; they are expected in Colorado). s = sometimes

	B. ascendens	B. campestre	B. echo	B. hesperium	B. lanceolatum	B. lineare	B. lunaria	B. matricariifolium	B. minganense	B. pallidum	B. "parsley"	B. pinnatum	B. simplex
Habit													
Plants waxy or matte (glaucous)	x	x		x		x				x			
Plants bright to dark green			x		x		x		x		x	x	
Trophophore stalked				x			s						
Trophophore attached at ground level							s						x
Trophophore firm or fleshy	x	x	s	s	x	x		?			x		s
Sporangia attached to lowest trophophore segments	s		s	s									s
Trophophore 2 or more x longer than wide	x	x	s	s		x	x	x	x	x	x	x	
Trophophore less than 2x longer than wide			s	s	x								x
Usually red stem			x		x		x					x	
Pinnae characteristics													
Pinnae fan-shaped	x						x		x		x		
Pinnae segments overlapping	s			s			x		s		s	s	x
Lowermost pair of pinnae strongly ascending in live material	x				x								s
Pinnae segments not or barely overlapping	x	x	x	s	s	x		x	x	x	x		
Pinnae segments lacerate	x						s				x		
Pinnae segments entire			s				s		x	x			
Pinnae segments lobed (not pinnate!)			s	s					s	s			
Pinnae segments strongly concave in life			s	x									
Lowest pinnae segments pinnately divided			s	s	x			x				x	
Lowest pair of pinnae markedly larger than next upper pair				x	x								x
Pinnae segments tending to be rounded in outline			x	x				x	x	x			
Pinnae narrow, rectangular, truncate	s	x				x			s	s			
Ecology													
Plants of moist sites					x	x	x	?	x	x	x	x	
Plants of dry sites	?	x	x	x	x		x					?	x
Low elevations (foothills to montane)		x	s		?	x	?	?					
Higher elevations (montane to alpine)	x		x	x	x	?	x		x	x	x	x	x
	B. ascendens	B. campestre	B. echo	B. hesperium	B. lanceolatum	B. lineare	B. lunaria	B. matricariifolium	B. minganense	B. pallidum	B. "parsley"	B. pinnatum	B. simplex

4.2 Habitats

Most species of *Botrychium* are ruderal, i.e., they are found in disturbed habitats. In Montana (pers. obs.), species are often found in roadsides, old logging landings, and on overgrown roadbeds, often in association with *Fragaria virginiana*, *Penstemon confertus* and *Gentianella amarella*. Some species (*B. hesperium*, *B. michiganense*) appear to prefer old overgrown alluvium, while others occur in upland habitats and have even been found in alpine tundra (C. Damm, pers. comm.). Only a few species are commonly found in forests, but only one (*B. montanum*) appears to be largely restricted to forests (although it has also been found in *Carex* fens in northeastern Oregon; D. Farrar, pers. comm.).

There are few studies of ruderal plant communities in which *Botrychium* occur. Wagner & Wagner (1983) reported on the tendency of moonworts to occur in what he termed "genus communities". These are communities where several to many *Botrychium* species co-inhabit the same site, a phenomenon which is as yet not satisfactorily explained. Perhaps they are dependent on the same mycorrhizal partner. The Wagners provided little information on other associated plants.

Numerous field workers have noted the tendency of moonworts to occur with strawberries (*Fragaria virginiana*), and this has been found to hold true in Alaska, British Columbia, Montana, Colorado, the Great Lakes region and even Iowa. *Fragaria virginiana* is a common theme in native ruderal plant communities throughout the Rocky Mountains, but plant associations are likely to be different in different regions.

In Europe, Muller (1991) studied the phytocoenoses in which the there rare species *B. matricariifolium* occurs in the Vosges region of northeastern France. He found that *B. matricariifolium* occurred in secondary, anthropogenic grasslands of the association *Viscario – Avenetum*, in the class of sparsely vegetated short grasslands (*Sedo-Scleranthetea*).

We sampled thirteen different sites in which rare moonworts were found in Summit County. Moonworts were always found in non-forested and disturbed habitats. The length of time since disturbance varied from site to site, but all sites had experienced disturbance in the last 2 to 100 years, often very severe forms of disturbance such as grading. Moonworts in general were found to be common in ski runs at the major ski resorts and in areas which had been burned in the adjacent areas in the past 100 years, which the canopy had not yet grown closed and where sparse grass communities occupy open gravelly slopes. These communities are described here as a provisional new association.

Festuco – Heterothecetum pumilae, assoc. nov. prov. (Table 3)
Fescue – Dwarf Golden Aster Community

Character species: *Botrychium echo*, *B. lanceolatum*, *B. lunaria*, *Heterotheca pumila*, *Cirsium eatonii* and possibly other *Botrychium* species.

This community occurs in the areas described above and is characterized by open, sparse vegetation with much bare, well-drained, compacted soil occurring on relatively gentle to

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moderate slopes in areas cleared of trees in the upper montane to subalpine zones. It is a ruderal community both in natural and anthropogenic habitats. Table 3 presents relevés from a number of different sites and is heterotoneous; further sampling may show differentiation in the community at the level of subassociation or variant.

Species with high constancy are *Arabis drummondii* (usually in low cover), *Achillea lanulosa, Trisetum spicatum, Androsace septentrionalis, Antennaria rosea, Epilobium angustifolium, Cirsium eatonii, Fragaria virginiana, Gentianella acuta, Potentilla diversifolia, Taraxacum officinale, Botrychium echo* and the lichen *Cladonia cariosa.*

The community is named for *Festuca brachyphylla* and *Heterotheca pumila*, which are both well-represented in natural stands of the community.

Contrary to popular perception, moonworts are not wide habitat generalists but are restricted to specific environmental circumstances. Almost all sites of the *Festuco – Heterothecetum* had the following characteristics in common:

- open sites, much direct sunlight
- 10-40% bare soil exposed, rock cover frequently 5-15%
- 20-30% slopes
- most aspects, except south
- always have history of disturbance (ruderal sites)
- always in areas with a coniferous forest potential natural vegetation, which were forested in past times
- most frequent in areas of sedimentary (calcium-containing) rock
- upper montane to subalpine, elevs. 3210-3510m (10500-11500 ft.), rarely to 3650m (12000 ft)
- primary habitats are mesic, plants occasionally found on dry and wet secondary habitats
- sites well-drained, soils compact and eroded

Olgeirson (1974) studied this and similar communities on Boreas Pass and found erosional processes to play a major role in the formation of the vegetation pattern. He attributed the erosion to late spring soil frost activity, summer needle ice and winter snow blast. Evidence of moderate to extreme erosion is found in almost all sites of the fescue – golden aster community.

Similar communities have been cursorily described by Olgeirson (1974) as the *Festuca ovina* (= probably our *brachyphylla*)-*Achillea lanulosa* lag gravel/buried brown podzolic regression complex and the *Carex foenea – Vaccinium scoparium* (=probably *myrtillus*) Brown Podzolic Regression complex, although the summary nature of his vegetation table limits the ability to compare floristic composition.

Komárková (1979) described related communities from the low alpine belt of the Indian Peaks Wilderness, and created for them the alliance *Vaccinio – Danthonion intermediae.* Her communities contain more alpine taxa and she does not report *Botrychium* species occurring in them.

It is likely that *Festuco – Heterothecetum* belongs in a western North American class of ruderal vegetation vicariant to *Sedo-Scleranthetea* from Europe and perhaps characterized by *Fragaria virginiana* and *Androsace septentrionalis*.

4.2 Population viability

A population viability analysis (PVA) seeks to answer the questions, what is the minimum number of plants necessary to perpetuate a species into the future? What are the factors that affect this number, and what are the current trends in the species in question? The few examples of PVAs of plants are in-depth, multi-year studies which focused on comparatively well-known and well-marked species (e.g., Menges 1990; Menges & Dolan 1998). In addition, PVAs for plants tend to be aimed at explaining or predicting sometimes alarming downward trends in populations and species numbers of threatened or endangered plants, brought about by fragmentation or isolation of populations (Dannemann et al. 1999; Morris et al. 1999).

The case of *Botrychium* species in Summit County, Colorado differs from most other rare plant PVAs and most rare plant conservation strategies in several respects. For one, several of the species found in Summit County are fairly abundant, and new populations are found frequently. At least with some species, their "rarity" may be more attributable to their inconspicuousness, recent taxonomic recognition and the lack of documentation than to real rarity on the landscape. Secondly, they occupy and sometimes even seem to prefer artificial, human-created habitats such as ski runs, and in doing so lead one to the conclusion that they are spreading into such habitats, and that their populations are, as a result, increasing. Finally, moonworts reproduce and disperse much differently than seed plants and even other ferns, with subterranean gametophytes (Farrar 1998a, 1998b) and occasionally even asexually through gemmae (Farrar & Johnson-Groh 1990).

In order to assess whether or not *Botrychium* populations are viable, one must consider species individually, but also look at the characteristics of the group as a whole. This is not an easy task given 1) the paucity of information about demographic trends, 2) an as yet rapidly changing knowledge of their distribution and occurrence and even taxonomy, and 3) the persistent difficulties of reliably identifying plants in the field, and therefore reliably counting numbers per species. The following discussion will seek to lay out what is known and what is not known at the present time about moonwort populations in Summit County.

Habitat

Knowledge of the plant communities and ecological requirements of a rare plants species are often used as a surrogate for more specific knowledge of population demographics (Poschlod et al. 1999).

As has been already discussed, moonworts occur primarily in disturbance-derived habitats (Lesica & Ahlenslager 1996), both natural and anthropogenic. In the central Rocky Mountains, all of the species of *Botrychium* subg. *Botrychium* are restricted to disturbed successional habitats,

created by sometimes severe disturbance and eventually overcome by succession to become forests or other more structurally complex plant communities. Prior to European settlement of the Rocky Mountains, moonworts were likely to have been infrequent in the region, found chiefly in such habitats as old burns, river bars and avalanche chutes, where they are also found today. Following the construction of roads and highways, the digging of mines and the construction of winter sport facilities such as ski resorts, the availability of disturbed sites for colonization greatly increased. Plant communities previously uncommon and restricted to the natural disturbed sites spread out into these areas and, in combination with a wave of arriving exotic plants, formed new plant communities in the anthropogenic, disturbed habitats. Whether or not natural habitats have become less common as a result of fire suppression is unknown.

It can be speculated that, due if nothing else to the appearance that available habitat has greatly increased from pre-European settlement conditions, numbers of individuals of *Botrychium* have also been on an increase in the last 100 years. If this is the case, recruitment of new individuals is inevitably taking place at a greater rate than individuals are dying. In other words, overall numbers very likely have been and may continue to be on the increase. A useful exercise would be to map natural and anthropogenic potential *Botrychium* habitats based on plant communities and compare acreage of natural versus real suitable habitat for *Botrychium* species.

Of the estimated 26,000 moonwort plants of all species known from Summit County, 19,000 are in anthropogenic habitats or have been highly affected by human influence in the past 50 years (Table 4). This is due at least in part to sampling bias, since much of the recent survey work has been concentrated in ski runs.

In the case of *Botrychium*, as with the endangered plant *Pedicularis furbishiae* (Menges 1990), habitat dynamism is at once both beneficial and detrimental to populations: individual populations may be destroyed by disturbance, but future habitats are also created, without which the entire population may trend towards extinction anyway.

Population attributes

In addition to generalizations about species reproductive biology and habitat trends, there are specific population attributes which must be taken into consideration when assessing population viability. These include individual plant number trends, number and distribution of populations, and their connectivity and isolation (Dannemann et al. 1999; Morris et al. 1999).

Spatial arrangement

Botrychium populations usually occur in "genus communities" (Wagner & Wagner 1983), aggregations of (sometimes closely related) species of the same genus growing side-by-side. The diversity of moonworts in single habitats is at least in part due to the allopolyploidy (speciation through hybridization), common in western moonworts (Farrar 1998a).

Another marked attribute of moonwort populations is that plants are concentrated irregularly in their preferred habitats, which is especially evident when plants are marked with coloured pin-flags in the field. Often acres of surrounding and connecting habitat are unoccupied except for scattered individuals but dozens or hundreds of moonworts may appear in a very small area. A possible explanation of this is the mycorrhizal relationship of *Botrychium* species, although the question might then turn to explaining the irregular distribution of the fungus.

Connectivity and Isolation

As discussed under the species' reproductive biology, the tendency of moonworts to be selfers and their long-distance spore dispersal would tend to lessen the significance of habitat connectivity, isolation and fragmentation. As off-site colonizers, moonworts are well-adapted to the colonization of new habitats and the bridging of habitat gaps. This is not the case with many other rare plants. Menges & Dolan (1998) discussed the effects of isolation and habitat fragmentation on a rare prairie plant, *Silene regia*, the limitations on its genetic interchange and the consequent effects on seed production and long-term viability. In this species, seeds are gravity-dispersed and consequently do not fall far from the parent plant. The rare plant *Pedicularis furbishiae* relies on seed dispersal for establishment of new populations (Menges 1990), and likewise lacks special dispersal mechanisms. Isolation and habitat fragmentation were also documented as effects on seed production in populations of *Biscutella laevigata* and *Muscari tenuiflorum* in Germany (Dannemann et al. 1999). These factors are likely of little concern for moonworts.

Demographics

As yet relatively little is known of population demographics in moonworts, aside from the studies of Lesica & Ahlenslager (1996) in Alberta, Muller (1991) in northeastern France and empirical observations. The ongoing work of C. Johnson-Groh (1998 and unpubl.), centered on Minnesota, perhaps goes the farthest in telling us about demographic trends in moonworts, confirming notions of prolonged dormant periods and the apparent non-critical nature of photosynthesis for the plants. The studies that have been undertaken point to rather short life cycles and comparatively rapid turnover in individuals (recruitment of new plants, death of old plants), at least in part dependent on disturbance. Experiments in roadside moonwort habitats in northern Michigan have shown that raking organic matter out of moonwort habitat and lightly scarifying the soil increased moonwort numbers significantly in subsequent years. Observation of a population of *Botrychium michiganense* and *B. hesperium* over more than 10 years at Great Northern Flats, Flathead County, Montana has shown consistently high number of plants on an abandoned roadbed without any recent additional disturbance. In northwestern Montana (pers. obs.), *Botrychium crenulatum* occurs frequently in roadbeds and logging landings which ceased to be used more than 10 years ago but disappears when the roadbed becomes too thickly revegetated; it also occurs on road shoulders and pullouts which experience infrequent use.

A common observation of people who survey for *Botrychium* is the year-to-year differences in populations size and abundance dependent on rain. Johnson-Groh (unpubl.) has correlated

population demographics with drought years in Minnesota moonwort populations. There, she found that populations dipped in the year(s) following a drought. There is one article, which we were unable to obtain (Serge Muller, The impact of a drought in spring on the sporulation of *Botrychium matricariifolium* [Retz.] A.Br. in the Bitcherland [northern Vosges, France], proposé pour publication dans *Acta oecologica*, but not found) which may shed further quantitative light on this topic.

Actual numbers

Individual plants and populations of *Botrychium* are quite abundant in Summit County, with over 26,000 plants estimated in the surveys of the past two seasons, including contract work on Copper Mountain and the present survey. However, it must be pointed out that 86% of these belong to two species, *B. lunaria* and *B. lanceolatum*. Table 4 provides a summary of moonwort numbers in Summit County.

Table 4. *Botrychium* population numbers in Summit County, estimates as of 13 Sept 2000.

Species	Est. number of stems	Number of sites	TNC global rank
B. lunaria	15157	16	G5
B. lanceolatum	7448	12	G4
B. echo	1079	8	G2
B. minganense	1854	8	G4
B. hesperium	567	7	G3
B. pallidum	150	4	G2
B. simplex	85	5	G5
B. pinnatum	151	2	G4?
B. "parsley"	22	2	?

The numbers of moonworts on a global scale are virtually inestimable. Numerous species are ranked as "globally secure" (ranks G4 to G5) by The Nature Conservancy (TNC) while a few are given lower rankings (Table 4). Of the species known to occur in Summit County, *Botrychium echo* (listed as G2, but probably deserving of G3 rank), *B. hesperium* (G3) and *B. pallidum* (G2) are accorded lower rankings. Species with a G (=global) ranking of 3 or less are considered to be globally rare (see TNC classification in Table 1). While no concrete estimations of numbers are available, these species can be assumed to have much smaller global numbers than G4 or G5 species.

5 Management Implications

Knowledge of moonworts in the southern Rocky Mountains is rapidly expanding with the discovery of new populations and the documentation of plant communities in which they occur. Known population numbers have increased almost exponentially in the last two years and can be

expected to further increase with further surveys. Informed observations can be made about moonwort reproductive biology, autecology and population biology but concrete demographic data are lacking. The following conclusions for the various *Botrychium* species are based on a consideration of the factors outlined above.

Botrychium lunaria, B. lanceolatum: The most numerous species in Summit County, globally secure and widespread on several continents, and common in disturbed areas. **Population viability is not believed to be of concern.** However, surveys should carefully try to separate aberrant types of *B. lunaria* and further sampling should be undertaken to ascertain the presence of any possible cryptic species.

B. echo, B. hesperium, B. minganense: These species are locally frequent where they are found in Summit County and potential (but as yet unsurveyed) habitat is (as with all moonworts) still very extensive. They are also frequent in ski runs and other anthropogenic habitats. *B. minganense* is widespread throughout North America and is relatively common in some areas, although it is near the southern limits of its range in Colorado. *B. hesperium* is widespread throughout the west, and *B. echo* is restricted to the southwest and Colorado. However, given the evident successful colonization of human-made habitats by these three species in Summit County ski areas, and their relative commonness in natural habitats, it appears there is substantial available and occupied habitat and that ground-disturbing activities create future habitat for these species. **Given these considerations and the relatively large numbers of plants involved, it is recommended that areas where these species occur be avoided, but if disturbance is unavoidable, a minimum threshold level of 1000 plants per species in Summit County should be maintained, in absence of a more detailed population viability analysis.** This figure is not based on any concrete minimum viable population (MVP) figures, as these are not known. However, given the comparative global rarity and sparse information on these species, a conservative approach is advised. With the present knowledge of populations this would represent a "zero take" situation for *B. hesperium*.

Botrychium simplex: Although believed to be a globally secure species, this species is highly variable in the western United States and may harbour cryptic taxa (W.H. Wagner, pers. comm. 1998). Colorado material looks somewhat different from Montana material and requires further study. The plant is one of the rarest moonworts in Summit County and is rare in Colorado according to present information. **In absence of more detailed population viability studies, populations of this species should be protected from ground-disturbing activities.**

Botrychium pinnatum: This species is very rare in Summit County and the actual number of plants may be even less than given in Table 4, because of frequent confusion with *B. hesperium "fenestratum"* type. It is globally secure and common in the main part of its range in northwestern North America. In Colorado it is very rare, although at least one of the sites is located in a ski run. **In absence of more detailed population viability studies, populations of this species should be protected from ground-disturbing activities.**

B. pallidum: This is the globally rarest species to be found in Summit County to date, with a TNC ranking of G2. As with other moonworts, the knowledge of the species is constantly increasing. However, only 150 plants have been found in Summit County. This may be due to the inconspicuous nature of this species and its tendency to be confused with *B. minganense*, or it may be attributable to real rarity. **It is recommended that all populations of this species be afforded maximum protection until the species, its ecology and disturbance requirements and population biology are better known.**

Unknown *Botrychium* species: Prior to and in the course of the present work, several plants were found which were difficult or impossible to name and which appear to be taxa (species, subspecies or varieties) not accounted for in the present overview of *Botrychium*. Perhaps they are new species for Colorado, or new to science altogether. Included in this is the form similar to *B. lunaria* termed "parsley-leaved" *Botrychium* (only 22 plants of this were found). **It is recommended that all populations of moonworts suspected of being unusual or new species be afforded maximum protection until, at a minimum, the identification of the species has been established.**

Management by the Forest Service

When faced with a conflict between natural resource management goals and rare plant populations, managers must decide between complete preservation of a plant population, impact to some, but maybe not to all individuals of a population, or complete destruction of a population. There are also mitigation measures which can be incorporated to modify either of the latter two options. Managers may decide on protection of compensatory habitat, more surveys or more research.

The following general guidelines are meant only as recommendations to managers and have no binding legal merit. However, they are based on knowledge of moonworts and moonwort habitats and the specific situation in Summit County. They are broadly similar to guidelines provided in the Conservation Assessment for moonworts of the Kootenai National Forest (Vanderhorst 1997).

1. Complete and detailed surveys should be undertaken whenever there is potential for *Botrychium* habitat to be impacted. Surveys should seek to document which species are present and in what numbers. This is in accordance with Forest Service Handbook guidelines on Sensitive plants and is standard practice.
2. All populations of *Botrychium pallidum*, *B. pinnatum* and *B. simplex* and of any unknown or suspected new moonwort should be afforded complete protection until more is known about them; extreme caution should be used in assessing impacts to individuals of *B. echo*, *B. hesperium* and *B. minganense*, while *B. lanceolatum* and *B. lunaria* do not appear to be of concern from a viability standpoint.

3. Important populations should be periodically monitored for demographics to document coarse trends in numbers, at a minimum every 10 years.
4. Surveys should be undertaken in potential or suspected moonwort habitats outside of proposed project areas to try to determine the full extent of populations in Summit County.
5. Moonwort habitat characteristics identified in this report should be further developed with more relevés in moonwort habitats. Ideally, 50-60 relevés would be needed to develop a more refined view of plant communities in which *Botrychium* species occur. Currently, there are only 13 such relevés.
6. The next logical step would be the development of maps of potential *Botrychium* habitats based on the plant communities in which they are found. This could be accomplished through interpretation of aerial photos, geological maps, elevational bounds and factors decisive in the distribution of moonworts. A map of potential moonwort habitats would allow quantification of habitat and a more accurate assessment of any potential impacts to the overall landscape picture should they occur.
7. Any future population viability work will require knowledge of population demographics of moonworts. Fine-scale monitoring plots should be installed and monitored annually for at least 10 years to develop an idea of population trends within populations of some of the lesser-known species (*B. echo, B. hesperium, B. pallidum, B. simplex*), including tracking of the fates of individual stems to show recruitment, death, dormancy, etc. There may be room for collaboration with Cindy Johnson-Groh, Gustavus Adolphus College, and her students in this task.
8. Experimental studies should be conducted on *Botrychium* habitats in conjunction with monitoring of population numbers. For instance, populations of *Botrychium* under approximately equal environmental conditions should be subjected to different types of management (perhaps natural snow vs. artificial snow, soil scarification vs. no soil scarification, etc.). Studies should also try to establish how long it takes for *Botrychium* species to colonize a site and how long it is before an above-ground plant appears.
9. The current transplant experiments at Copper Mountain and Breckenridge in sites where moonworts are being removed to allow management and then replanted should be carefully monitored and their results should be shared with the scientific community.

6 Acknowledgments

We wish to thank Mike Liu, Nancy Redner and Rick Thompson for information about *Botrychium* populations in Summit County. Don Farrar is thanked for his detailed review of the September 2000 draft of this report and for electrophoretic analysis of several samples gathered during the late summer of 2000. W.A. Weber was of great assistance with the identification of associated plants and also provided a detailed review of the September 2000 draft of this report. Florence Wagner reviewed identifications of some moonwort samples based on photocopied profiles. Andy Kratz is also thanked for reviewing the document.

7 Literature Cited

Dannemann, A., Jackel, A.-K., Weiß, G., Poschlod, P., Mahn, E.-G. (1999): Auswirkungen räumlicher Isolationsmechanismen auf Pflanzen – Grundlagen und ausgewählte Beispiele (*Biscutella laevigata* L. und *Muscari tenuiflorum* Tausch). pp. 70-78 *in* Amler, K., Bahl, A., Henle, K., Kaule, G., Poschlod, P. & Settele, J. (eds.): *Populationsbiologie in der Naturschutzpraxis: Isolation, Flächenbedarf und Biotopansprüche von Pflanzen und Tieren.* Eugen Ulmer Verlag, Stuttgart (Hohenheim).

Farrar, D.R. & Johnson-Groh, C.L. (1990): Subterranean sporophytic gemmae in moonwort ferns, *Botrychium* subgenus *Botrychium*. *Amer. J. Bot.* 77(9): 1168-1175.

Farrar, D.R. (1998a): Isozyme characterization of moonwort ferns (*Botrychium* subgenus *Botrychium*) and their interspecific relationships in northwestern North America. Draft final report submitted to Kootenai National Forest, 30 Jun 1998. 15 pp.

Farrar, D.R. (1998b): Population genetics of moonwort Botrychiums. pp. 109-113 *in* Berlin, N., Miller, P., Borovansky, J., Seal, U.S. & Byers, O. (eds.) *Population and habitat viability assessment workshop for the goblin fern* (Botrychium mormo). Final report, Conservation Breeding Specialist Group (Apple Valley, Minnesota).

Farrar, D.R. (2000): A genetic assessment of the systematic relationships of western moonwort species (*Botrychium* subg. *Botrychium*). Unpublished report submitted to Colville and Tongass National Forest. 5 pp.

Johnson-Groh, C. (1998): Population demographics, underground ecology and phenology of *Botrychium mormo*. pp. 103-108 *in* Berlin, N., Miller, P., Borovansky, J., Seal, U.S. & Byers, O. (eds.) *Population and habitat viability assessment workshop for the goblin fern* (Botrychium mormo). Final report, Conservation Breeding Specialist Group (Apple Valley, Minnesota).

Komárková, V. (1979): *Alpine vegetation of the Indian Peaks area, Front Range, Colorado Rocky Mountains.* Flora et vegetatio mundi 7. Cramer, Vaduz. 591 pp. + table volume

Lesica, P. & Ahlenslager, K. (1996): Demography and life history of three sympatric species of *Botrychium* subg. *Botrychium* in Waterton Lakes National Park, Alberta. *Can. J. Bot.* 74(4): 538-543.

Menges, E.S. (1990): Population viability analysis for an endangered plant. *Conservation Biology* 4(1): 52-62.

Menges, E.S. & Dolan, R.W. (1998): Demographic viability of populations of *Silene regia* in midwestern prairies: relationships with fire management, genetic variation, geographic location, population size and isolation. *J. Ecol.* 86: 63-78.

Morris, W., Doak, D., Groom, M., Kareiva, P., Fieberg, J., Gerber, L., Murphy, P. & Thomson, D. (1999): *A practical handbook for population viability analysis.* The Nature Conservancy. 80 pp.

Muller, S. (1991): Etude des phytocénoses à *Botrychium matricariifolium* (Retz.) A.Br. du Pays de Bitche (Vosges du nord). Application à la mise au point des modalités de leur gestion conservatoire. *Bull. Soc. Bot. Fr.* 138, *Actual. Bot.* (2): 147-158.

Olgeirson, E. (1974): Parallel conditions and trends in vegetation and soil on a bald near treeline, Boreas Pass, Colorado. Arct. Alp. Res. 6(2): 185-203.

Oostermeijer, G., Luijten, S., Kwak, M., Boerrigter, E., Den Nijs, H. (1998): Rare plants in peril: on the problems of small populations. *Levende Natuur* 99(4): 134-141.

Poschlod, P., Dannemann, A., Jackel, A.-K., Bonn, S. (1999): Fragmentierung und Isolation von Pflanzenpopulationen – Einführung und Konzepte. pp. 67-70 *in* Amler, K., Bahl, A., Henle, K., Kaule, G., Poschlod, P. & Settele, J. (eds.): *Populationsbiologie in der Naturschutzpraxis: Isolation, Flächenbedarf und Biotopansprüche von Pflanzen und Tieren.* Eugen Ulmer Verlag, Stuttgart (Hohenheim).

Root, P. (undated): Colorado moonwort guide. Unpublished MS, 9 pp.

Spackman, S., Jennings, B., Coles, J., Dawson, C., Minton, M., Kratz, A., Spurrier, C. (1997): Colorado rare plant field guide. Colorado Natural Heritage Program. Pages unnumbered.

Vanderhorst, J. (1997): *Conservation assessment of sensitive moonworts* (Botrychium *subgenus* Botrychium) *on the Kootenai National Forest.* Montana Natural Heritage Program, Helena, MT. 82 pp. + appendices.

Wagner, W.H. & Wagner, F.S. (1983): Genus communities as a systematic tool in the study of New World *Botrychium* (Ophioglossaceae). *Taxon* 32(1): 51-63.

Wagner, W.H. & Wagner, F.S. (1986): Three new species of moonworts (*Botrychium* subg. *Botrychium*) endemic in western North America. *Amer. Fern J.* 76(2): 33-47.

Wagner, W.H. & Wagner, F.S. (1993): Ophioglossaceae, Botrychium. Pp. 85-101 *in* Flora of North America Editorial Committee (eds.): *Flora of North America North of Mexico.* Vol. 2. Oxford Univ. Press.

Wagner, W.H. & Wagner, F.S. (1994): Another widely disjunct, rare and local North American moonwort (Ophioglossaceae: *Botrychium* subg. *Botrychium*). *Amer. Fern J.* 84(1): 5-10.

Weber, W.A., & Wittmann, R.C. (1992): *Catalog of the Colorado flora: a biodiversity baseline.* University Press of Colorado. 215 pp.

Westhoff, V. & van der Maarel, E. (1978): The Braun-Blanquet approach. in Whittaker, R. (ed.) *Classification of plant communities.* Kluwer, Den Haag.